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Energy production, consumption, and environmental pollution for sustainable development: A case study in Turkey

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Abstract

There is increasing consensus in both the scientific and political communities that significant reductions in greenhouse gas (GHG) emissions are necessary to limit the magnitude and extent of climate change. Renewable energy systems already reduce GHG emissions from the energy sector, although on a modest scale. Most long-term energy projections show that renewable energy will play a major role in the global energy supply in the second half of the century, with capacity increasing gradually in the first three decades. On the other hand, Turkey is heavily dependent on expensive imported energy resources (oil, gas and coal) that place a big burden on the economy and air pollution is becoming a great environmental concern in the country. In this regard, renewable energy resources appear to be one of the most efficient and effective solutions for clean and sustainable energy development in Turkey. Turkey's geographical location has several advantages for extensive use of most of these renewable energy sources. This article presents a review of the potential and utilization of the fossil fuels and the renewable energy sources in the world and in Turkey.

Keywords: Renewable energy; Geothermal; Hydropower; Solar and photovoltaics; Biomass

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Contents

1. Introduction

Energy is essential to economic and social development and improved quality of life in all countries. Much of the world's energy, however, is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to increase substantially. The need to control atmospheric emissions of greenhouse and other gases and substances will increasingly need to be based on efficiency in energy production, transmission, distribution and consumption in the country. Electricity supply infrastructures in many developing countries are being rapidly expanded as policymakers and investors around the world increasingly recognize electricity's pivotal role in improving living standards and sustaining economic growth [1–3].

Climate change is a global challenge with serious consequences for our social and economic infrastructure as well as the natural environment. The greenhouse gas (GHG) emissions that cause climate change are emitted mainly from burning fossil fuels such as

coal, oil and natural gas. Because heavy industry is a leading source of GHG emissions, most of the business-focused programs responding to the problem emphasize participation by "emitters," manufacturers and utilities. Action by industry alone, however, is not enough. Long-term solutions require emission reduction efforts by the entire economy, and this publication addresses service-sector companies such as banks, law firms, retailers, and real estate managers. Even though they are not considered large emitters, these companies do emit GHGs and can help mitigate climate change through changes in their energy use and the products and services they offer. On the other hand, renewable energy sources are sufficiently abundant that they potentially could provide all of the world's energy needs foreseen over the next century [4–9].

2. Global energy consumption

World primary energy demand is projected in the Reference Scenario to expand by almost 60% from 2002 to 2030, an average annual increase of 1.7% per year. Demand will reach 16.5 billion tons of oil equivalent (toe) compared to 10.3 billion toe in 2002 (Table 1). The projected *rate* of growth is, nevertheless, slower than over the past three decades, when demand grew by 2% per year. On the other hand, fossil fuels will continue to dominate global energy use. They will account for around 85% of the increase in world primary demand over 2002–2030. And their share in total demand will increase slightly, from 80% in 2002 to 82% in 2030. The share of renewable energy sources will remain flat, at around 14%, while that of nuclear power will drop from 7% to 5% [10–12].

Oil will remain the single largest fuel in the global primary energy mix, even though its share will fall marginally, from 36% in 2002 to 35% in 2030. Demand for oil is projected to grow by 1.6% per year, from 77 mb/d in 2002 to 90 mb/d in 2010 and 121 mb/d in 2030. Oil use will become increasingly concentrated in the transport sector, which will account for two-thirds of the increase in total oil use. Transport will use 54% of the world's oil in 2030 compared to 47% now and 33% in 1971. In OECD countries, the use of oil in the residential and services sector will decline sharply. In non-OECD countries, transport will also be the main driver of oil demand, though the industrial, residential and services sectors will also see steady oil-demand growth. In many developing countries, oil products

Table 1
World total final consumption (Mtoe)

	1971	2002	2010	2030	2002–2030 (%)[a]
Coal	617	502	516	526	0.2
Oil	1893	3041	3610	5005	1.8
Gas	604	1150	1336	1758	1.5
Electricity	377	1139	1436	2263	2.5
Heat	68	237	254	294	0.8
Biomass and waste	641	999	1101	1290	0.9
Other renewables	0	8	13	41	6.2
Total	4200	7075	8267	11,176	1.6

Source: Ref. [12].

[a]Average annual growth rate.

will remain the leading source of modern commercial energy for cooking and heating, especially in rural areas [12].

Primary demand for natural gas will grow at a steady rate of 2.3% per year over the projection period. By 2030, gas consumption will be about 90% higher than now, and gas will have overtaken coal as the world's second-largest energy source. The share of gas in total primary energy use will increase from 21% in 2002 to 25% in 2030. The power sector will account for 60% of the increase in gas demand, with its share of the world gas market rising from 36% in 2002 to 47% in 2030. The power sector will be the main driver of demand in all regions. This trend will be particularly marked in developing countries, where electricity demand is expected to rise most rapidly. Natural gas will remain the most competitive fuel in new power stations in most parts of the world, as it is the preferred fuel for high-efficiency combined-cycle gas turbines (CCGTs). A small but growing share of natural gas demand will come from gas-to-liquid plants and from the production of hydrogen for fuel cells [10–12].

Coal use worldwide is projected to increase by 1.5% per year between 2002 and 2030. By the end of the 2004, coal demand, at just over 7 billion tons, will be just about 50% higher than at present. The share of coal in total primary energy demand will, nonetheless, fall slightly, from 23% to 22%. Coal consumption will increase slowly in end-use sectors. Industry, households and services in non-OECD regions will use more coal, more than offsetting a continuing decline in OECD final consumption.

The role of nuclear power will decline progressively by the end of 2004. The rate of construction of new reactors is expected to keep pace with the rate at which old reactors are retired. This is both because nuclear power will have trouble competing with other technologies and because many countries have restrictions on new construction or policies to phase out nuclear power. As a result, nuclear production will peak soon after 2010 and then decline gradually. Its share of world primary demand will drop from 7% at present to 6% in 2010 and to 5% by 2030. Nuclear output will increase in only a few countries, mostly in Asia. It is projected to fall in Europe. These projections are, however, subject to considerable uncertainty. Possible changes in government policies on nuclear power and public attitudes toward it could lead to nuclear power playing a much more important role than projected here.

Global primary energy demand is projected to expand at almost the same average annual rate over the projection period. However, there are notable differences among fuels. In particular, demand for natural gas is now projected to grow less rapidly due to higher gas prices and to more use of renewables and nuclear power in power generation. On the other hand, global energy intensity, expressed as total primary energy use per unit of gross domestic product, will fall by 1.5% per year over 2002–2030. Intensity will fall in all regions, though at different rates. Significant differences in intensity among regions will persist, reflecting differences in the stage of economic development, the energy efficiency of end-use technologies, economic structure, energy prices, climate, geography, culture and lifestyles. Intensity will fall most steeply in the transition economies [10–12].

3. Sustainable energy for development

Access to modern energy services is a central precondition for poverty reduction and development. Energy will help people to become more productive in their work and to

raise their income [9]. Small businesses will be given new opportunities to foster production and generate income. Ever since the beginning of the industrial age the countries of the North have used huge amounts of fossil fuels for their development. The ensuing burden on the environment and the threats to the global climate are also very well known. The problem is currently being exacerbated, as the developing, newly industrialized and transition countries are trying to catch up in economic terms, basing this process on conventional energy technologies. Thus, promoting renewable energies and exploring energy saving potentials as an alternative approach in all parts of the world is becoming increasingly urgent [13–16].

The main responsibility of the developing technologies for a sustainable global energy system and preparing them for marketing lie with the industrialized countries. However, the developing countries can and should be encouraged to participate in this global task. In this context one merely has to recall the favorable natural conditions in these countries that would facilitate the use of renewable energies, such as solar irradiation in desert regions, wind potential along the shores of many countries and the geothermal potential of the Rift Valley.

3.1. Future prospects for the poor population

Electricity generated from renewable sources can be fed into large grids, but the biggest advantages of renewable energies lie in its decentralized use. Here, the benefits of renewables truly come to bear. Particularly in poor rural areas where it would be uneconomical to set up an electricity network, renewable energy can offer new prospects to the rural population and thus make a valuable contribution to the fight against poverty. Renewable energies can help many developing countries to reduce their dependency on fossil fuel imports and the financial stress caused by price fluctuations on the world market [9,11].

At the World Summit on Sustainable Development in Johannesburg in 2002 the German government sent out an important signal and up to 2007, 1 billion euros will be allocated to sustainable energy projects in the context of development cooperation. Of this amount, 500 million euros are earmarked for projects aimed at enhancing renewable energies in developing countries, while the remaining 500 million euros will be used for increasing energy efficiency in these countries. The aim of this program is to help the partner countries to gain improved access to environmentally friendly energy, to overcome poverty and to substitute types of energy generation that are detrimental to our climate and the environment with ecologically sound alternatives [11–13].

4. Energy: the world needs renewables

Sufficient energy supply is a central factor for the economic development of any country. The poor can benefit most from access to modern types of energy. The development and expansion of an energy supply system is an important contribution to achieving the goals of the UN Millennium Declaration. Renewable energies, next to technologies for improving energy efficiency in developing countries, measure up to these goals. They facilitate decentralized access to energy, so that even in remote regions the issue of energy supply will no longer constitute an obstacle to development. But also from a global perspective renewable energies offer many benefits: they help to

reduce CO_2 emissions, thus promoting climate protection. They replace fossil fuels, therefore reducing the economic dependency on energy imports that many nations struggle with [15–18].

The world is faced with an immense challenge: the population and its food, commodities and service requirements are continuously growing. This is paralleled by a heavily increasing demand for energy. According to forecasts by the International Energy Agency (IEA) in Paris, by 2030 global energy consumption will have increased by another 60%, compared with 2001 levels. At the same time it will become more and more difficult to meet these energy demands chiefly from fossil resources. Experts predict that petroleum could become so scacre within the next 20 years that prices will soar. This entails an incalculable risk for those countries which in the future will still be largely dependent on energy imports. In addition, the combustion of petroleum, natural gas and coal poses a hazard to the environment and the global climate [14–16].

In future the world's energy supply must become more sustainable. This means that it must meet the basic needs of the poor worldwide without using up in this process the limited natural resources to the detriment of future generations. This can be achieved both by a more efficient use of energy and by relying on renewable sources of energy, particularly wind, hydropower, solar and geothermal energy and biomass. So far, the potential of these types of energies has been used to only a minor extent.

At present, renewable energies account for less than 14% of the worldwide total primary energy supply. However, a large share of this amount is based on the traditional and often unsustainable use of biomass. The potential of advanced renewable energies is by far greater. For example, the earth receives enough energy from the sun to meet the total energy requirements of our planet 15,000 times over—in theory. The point is now to access a fraction of this potential and to put it to use for humankind. Experts say that in practice about half of the global energy demand could be met by renewable sources by the year 2050 [17–19].

Renewable energy is multifarious, ranging from huge hydropower plants and wind farms for electricity production to small photovoltaic (PV) installations that operate water pumps not connected to the grid or that serve as a power source for individual homes or small settlements in the guise of solar home systems. Biogas can be used for cooking, geothermal power offers a cost-efficient method for heating and for electricity generation [8].

In many developing and newly industrialized countries energy supply so far has been insufficient. Vast regions are not connected to a national electricity network. The population traditionally satisfies its energy requirements largely from natural sources, mostly wood. That contributes to deforestation, leading to massive environmental problems in many places, because without vegetation cover the soil erodes. This constitutes a major obstacle to economic development in these countries [20].

More than two billion people worldwide have no access to modern types of energy. Other than fuel wood they resort to batteries, candles and kerosene, amongst others. The purchase of these goods involves a considerable financial burden. Even though poor people on average need only 1 kilowatt-hour (kWh) per day, they often have to spend approximately one third of their income on it. Access to advanced energies offers people new opportunities to spend their meager income on other goods. At the same time, once they are hooked up to a power supply system, craftspeople and other small businesses gain access to new production opportunities and sources of income [11].

5. Renewable energies for climate protection

The most common GHG is carbon dioxide (CO_2) and two of the largest global sources are electricity and heat (32%) and transportation (17%). Service-sector companies' activities contribute to these sources through their electricity use, heating, cooling and travel. They may also contribute to other large global CO_2 emission sources such as land use change and forestry (24%) and manufacturing and construction (13%). Service-sector companies have an opportunity to influence their operations, supply chains, customers, employees, and other stakeholders and to help change those behaviors necessary to curb the most dangerous effects of climate change [20,21].

Since the beginning of the industrial age, growing quantities of gases have been released into the atmosphere with the ability to trap sunlight and thus with the potential to cause an increase in the mean global temperature. A temperature increase of just a few degrees will lead to climate changes that have the potential to cause irreversible ecological impacts with enormous accompanying economic and social dislocations. Global warming is of course the reason why there is a need to avoid producing CO_2. Gases like CO_2 travel up into the upper atmosphere (the troposphere) where they act as a screen to sunlight. They allow the suns rays in but stop the heat radiation from re-emerging, much as happens with the glass in greenhouse. The result is that the greenhouse, in this case the whole world, heats up. Table 2 shows environmental impacts of the present energy system. Some degree of global warming is actually vitial, otherwise this planet would be too cold to support life. However, the vast tonnage of CO_2 gas we have released into the atmosphere seems likely to upset the natural balance. Table 3 also shows world CO_2 emissions by region [19–21].

Since the onset of industrialization the CO_2 content in the atmosphere has gone up by approximately 30%. This increase is also to be attributed to human activity. In the course of the past 100 years it is mostly the industrialized countries that have burned huge amounts of coal, petroleum and natural gas, causing the release of large quantities of CO_2 into the atmosphere [7]. CO_2 is a GHG that makes temperatures near the ground rise. Worldwide, on average temperatures have gone up by 0.6 °C during the past 100 years and in recent years there has been a discernible increase in severe weather events such as

Table 2
Environmental impacts of the present energy system

Energy source	Inherent		Avoidable	
	Global	Local	Global	Local
Coal	CO_2	Mining	Acid rain	Air pollution
Oil	CO_2		Ocean pollution	Air pollution, local water resources
Gas	CO_2		Greenhouse gases due to leaking pipelines	
Hydropower		Aquatic ecosystems/ competition with other water usage		Aquatic ecosystems/ competition with other water usage
Nuclear	Non-proliferation	Accidents/political stability		Radioactive waste

Source: Ref. [7].

Table 3
World carbon dioxide emissions by region, 1990–2025

Region	1990	2002	2010	2015	2020	2025
Mature market economies	10,465	11,877	13,080	13,745	14,392	15,183
North America	5769	6701	7674	8204	8759	9379
Western Europe	3413	3549	3674	3761	3812	3952
Mature market Asia	1284	1627	1731	1780	1822	1852
Transitional economies	4894	3124	3643	3937	4151	4386
Emerging economies	6101	9408	13,478	15,602	17,480	19,222
Asia	3890	6205	9306	10,863	12,263	13,540
Middle East	845	1361	1761	1975	2163	2352
Africa	655	854	1122	1283	1415	1524
Central and South America	711	988	1289	1480	1639	1806
Total World	21,460	24,409	30,201	33,284	36,023	38,790

Source: Ref. [19].

storms, floods and droughts. If these trends are not reversed, by the end of the century the CO_2 content could rise to three times the level of the pre-industrial age. For the next 100 years the Intergovernmental Panel on Climate Change (IPCC) predicts further temperature rises of up to 5.8 °C [5–7].

Climate change will hit the developing world the hardest. On the one hand their sources of livelihood are extremely vulnerable. Many developing countries are predominantly agricultural. Severe weather events and changing climate conditions can entail major economic losses for them. On the other hand, very often they are lacking the capacities for adjusting to climate change, for instance by building protective dykes along their coastlines. Climate change poses a true existential challenge to the developing countries concerned, especially to the poorer part of the population [7].

In order to bring climate change to a halt or at least to alleviate its effects, a drastic reduction of CO_2 emissions is necessary. The main responsibility for this lies with the industrialized countries. They will have to convert to renewable and CO_2-free power production as soon as possible. Another important pillar of climate change policy is investments in improved energy efficiency. There is an enormous potential for this both in industrialized and in developing countries.

6. Different types of renewable energies

"Modern" renewable energies are based on progressive technologies. When linked to new technologies for saving energy, they are able to meet all the demands of environmental and climate protection. Renewable energies have an enormous potential. The calculated output of solar, wind, geothermal and hydropower as well as the modern use of biomass could generate enough energy to meet the demands of the world's population several thousand times over. From a practical point of view, so far only a few technologies for using renewable energies have proven to be competitive, while their economic viability is also limited to certain regions in the world. This is not only to be attributed to high investment costs for such technologies. Often, markets are strongly distorted by subsidies

in support of fossil fuels, leaving renewable energies at a disadvantage. Here, political solutions are needed that will help to quickly dismantle the obstacles renewable energies are confronted with. If the further development and application of these technologies are promoted systematically and policy-makers establish fair conditions in the energy market, great progress is only a matter of time [8,15,22].

6.1. Biomass

Biomass is the first type of renewable resource ever to be used for energy generation. As early as the stone age people gathered around a log fire for warmth. Today biomass still constitutes the most important renewable source of energy. Worldwide, around 2.4 billion people use firewood and charcoal for cooking and heating [20–26]. In Sub-Saharan Africa almost 90% of the total population are completely dependent on these fuels as their source of energy. Nonetheless, the traditional use of biomass brings with it many problems. On the one hand the energy content of biomass is used only very inefficiently, which means the consumption of burning material is high. On the other hand, open fireplaces pose a threat to human health. In developing countries, many women and children who spend year after year at smoky fireplaces in poorly ventilated huts suffer from respiratory diseases [23,24].

Therefore, in future the use of biomass needs to be made more efficient. Very often the relevant technologies are neither complicated nor expensive. Simple wood stoves as a replacement for open fireplaces or small biogas installations could greatly increase energy efficiency in developing countries. Biomass is more than just wood. Straw, animal dung, vegetable oil, biodiesel and biogas can also be used as a renewable energy source. The burning of biomass has one advantage over the combustion of fossil fuels: it releases no more CO_2 than the plants have previously absorbed from the air [27].

6.2. Hydropower

Hydropower is the only renewable energy source that can already boast a substantial share of today's electricity generation. Worldwide its share amounts to 17%, which corresponds roughly to the total energy supply of the EU [28]. In Latin America about three-quarters of energy requirements are met by hydropower. What makes this technology so attractive is, among other things, the low costs of electricity generation. In addition, in contrast to solar or wind power plants, hydropower plants produce energy without interruption—as long as there is enough water in the reservoir and droughts do not prevent the inflow of more water.

Hydropower can make considerable contributions to the increased use of renewable energies. However, for each new power plant construction project the issue of sustainability should be looked into very carefully, because the construction of new hydropower plants—especially of very large dams—interferes strongly with the natural and social balance in the regions. Such projects entail extreme burdens for the local population, if they have to stand by while their original area of settlement vanishes in the floods and they are given no adequate compensation [9].

Also, those living downstream are affected, because the new dam can dry up their traditional sources of income. For example, farmers may have reduced harvests due to a deteriorating soil fertility that is caused by the absence of regular flooding. Merchants and traders who used to travel the river by boat can no longer do so, as the dam is blocking

their way. On the other hand, the World Commission on Dams has developed new criteria for the social, environmental and development compatibility of new power plants. The Commission advises countries to only implement projects that are in line with these standards [9].

6.3. Wind power

In recent years wind power has experienced a veritable boom. Even though so far only an approximate figure of 0.04% of the worldwide total primary energy supply can be attributed to wind power, at present it shows the biggest growth rates among all types of renewable energies. Wind turbines have made such technological progress that in particular in wind-rich regions they can produce electricity at a competitive price comparable to conventional power plants. Wind power offers a strong economic potential for application in developing countries. Admittedly, investment costs are often higher than in industrialized countries, because the manufacturers have to pay more for transport, installation and maintenance of the plants, but these disadvantages are compensated for by excellent wind conditions at some of the sites. In addition, very often wind power can substitute expensive diesel fuel in power plants. The disadvantage of wind power plants, namely that they do not generate any electricity when there is no wind, is actually balanced by creating an energy mix in the national electricity grid. But wind power is also an interesting option in remote areas that are not connected to the grid. Wind turbines can be combined with a diesel generator [22–24].

6.4. Geothermal power

The enormous heat inside the earth can be used continuously for heating and electricity generation. Worldwide, geothermal power covers only a rough 0.5% of the total primary energy supply. However, its potential is nearly inexhaustible. Expert calculations suggest that theoretically more than ten times the global energy demand of today could be generated by geothermal power every year [25,26].

There are two different methods for using geothermal power. The first one is the hydro-geothermal method, where naturally occurring hot water reservoirs are tapped underground. The hot groundwater can be used for heating, and, when temperatures are high enough, also for the generation of electricity. The second method is the so-called hot dry rock method, which uses geothermal heat contained in rock. For that purpose water is pumped under high pressure into fractured hot plutonic rock. It heats up underground and returns to the surface via a second borehole. The water thus heated can then be used for generating electricity and heat.

The reasons why geothermal power up to now has hardly been used throughout the world have to do with uncertainties in assessing these underground resources and the exploration risks. In order to determine the geothermal potential of a region it is necessary to carry out expensive exploratory drillings, thus multiplying investment costs.

6.5. Solar power

Solar power is a type of energy with great future potential—even though at present it covers merely a minor portion of global energy demands (0.05% of the total primary

energy supply). At the moment PV power generates less than 1‰ of total electricity supply. This is due to solar power still being considered the most expensive type of renewable energies. However, in remote regions of the earth it may very well constitute today's best solution for a decentralized energy supply [28,29].

Solar energy can be used in two different ways: to generate heat (solar thermal application) or directly to generate electricity (PV application). In solar thermal applications water or another liquid runs through tubes that are heated by the sun. Installations that use mirrors to send concentrated sun rays to the heating containers are particularly efficient. The hot water can be used for heating, as warm process water or indirectly as water vapor for generating electricity. However, solar-based power generation is efficient only when carried out in large-scale power plants with large mirror panels. These panels can collect enough energy to heat the water sufficiently to activate the steam turbines [20–24].

In PV applications the energy of the sunlight is directly converted into electricity. To that end, special solar cells are needed. Today they are mostly made out of silicon. In future, though, it is conceivable that solar cells could be made from organic matter, which will be cheaper. Experts reckon that within a few decades solar cells will be efficient and economical enough to be competitive against all other types of energy. Since there are no moving parts, solar cells are very robust and low in maintenance, which makes them a particularly attractive type of decentralized energy supply system for developing countries rich in sunshine.

7. Energy efficiency

Renewable energies are not the only relevant factors for ensuring a sustainable energy supply worldwide. About 70% of the total worldwide primary energy used is lost throughout the energy supply chain, starting with the production and transport of energy all the way to its final consumption. There is huge energy-saving potential here. Without clearly improving energy efficiency the aims of sustainable energy management and a successful climate protection policy cannot be reached [9].

There are many ways to use energy more efficiently. In many cases it takes only simple tools to effect enormous improvements. For instance, brushwood can be used much more efficiently with a simple cooking stove as compared with an open fire. Better insulation reduces the energy needed for heating. Often it is better to step up the efficiency of existing power plants and to invest in energy-saving equipment for the end user than to spend money on new power plants [7,17].

Energy efficiency is also a particular concern of developing countries. On the one hand, there are many outdated power plants in these countries. With just a little extra input, such as an upgrade of the turbines, their energy efficiency can be clearly improved. On the other hand many developing countries are faced with the question of how to meet the increasing energy needs of the population. The most important point is the proper dimensioning of new supply systems to meet the demands. As a general rule, the more efficient the complete supply system is, the less power generation capacities is needed. Consequently, the need for investment diminishes. High energy efficiency is also beneficial for renewable energies. The less energy the population needs, the easier it will be to meet the demand from renewable sources—and the less money needs to be spent on expensive power plants and giant distribution grids.

8. Global renewable energy utilization

As renewable energy markets accelerate and policies multiply around the world, so do the environmental benefits. Use of renewable energy avoided the release of an estimated 0.9 billion tons of CO_2 emissions in 2004 and displaced about 3% of global power generation that would otherwise come from fossil fuels. However, environmental impact is only part of the picture. The $39 billion invested in renewable energy capacity worldwide in 2005, up from $14 billion in 2000, underscores that renewable energy has become big business. This investment is a significant percentage of the roughly $150 billion invested in all forms of power generation globally each year. More and more, renewable energy means investment and profit. A group of the 80 leading renewable energy companies was valued at more than $55 billion in market capitalization in 2006. The solar PV industry alone made an estimated $6 billion investment in new plant and equipment in 2005 as it expanded production by 50%. Although pronouncements like "renewable energy enters the mainstream" and "renewable energy comes of age" rarely capture headlines, when well-known firms make large investments in renewable energy. Table 4 shows renewable energy indicators [21–26].

Table 4
Renewable energy indicators

	Capacity
Indicator	End of 2005
Power generation	(GW)
Large hydropower	750
Small hydropower	66
Wind turbines	59
Biomass power	44
Geothermal power	9.3
Solar PV, off-grid	2.3
Solar PV, grid-connected	3.1
Solar thermal power	0.4
Ocean (tidal) power	0.3
Total renewable power capacity	934.5
Hot water/space heating	(GWth)
Biomass heating	220
Solar collectors for hot water/heating (glazed)	88
Geothermal direct heating	13
Geothermal heat pump	15
Households with solar hot water	40 million
Transport fuels	(litres/yr)
Ethanol production	33 billion
Biodiesel production	3.9 billion
Rural (off-grid) energy	
Household-scale biogas digesters	21 million
Household-scale solar PV systems	2.4 million
Solar cookers	1 million

Source: Ref. [23].

8.1. From fossil fuels to renewable energy

The world's energy supply has historically been dominated by fossil fuels. Today, 77% of global primary energy comes from fossil fuels, with the remainder from traditional biomass (9%), large hydropower (6%), nuclear (6%), and renewable energy (2%) [10]. Unfortunately, fossil fuel energy consumption has serious side-effects: environmental insults arising from the use of coal and petroleum in particular result in a growing number of human illnesses and ecosystem disruptions and represent a growing threat to society from climate change. For example, sulfur emissions to the atmosphere from human activities are on the order of 80 million tons per year, 85% from burning fossil fuels [21]. This compares to a natural baseline flow of about 30 million tons per year to the atmosphere. The results include acid rain, water and soil acidification, forest die-off, increases in human respiratory diseases and health costs, and loss of agricultural productivity. Lead emissions to the atmosphere from human activities are on the order of 0.2 million tons per year, 40% of that from fossil fuels and 18 times the natural baseline flow. About 2 million tons per year of oil are released into the oceans, 10 times the baseline of natural oil flow. The atmospheric concentration of CO_2, a primary GHG, has increased from 280 parts-per-million (ppm) in pre-industrial times to 380 ppm today. About 75% of human-caused emissions of CO_2 come from burning fossil fuels [20,21].

The environmental benefits of renewable energy are quite clear when renewable energy displaces conventional fossil-fuel power generation. These benefits can be quantified in reductions of direct emissions into the atmosphere of CO_2, sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulates, and heavy metals. Another way to quantify these benefits is by measuring the real economic costs of these environmental insults, called "external costs" by economists if not borne by energy producers or users. These external costs have been estimated by a recent European Commission study at between 2% and 12% per kWh for coal power plants. Thus, external costs can be double or triple the direct costs of base-load coal power (typically 3–4 cents per kWh). The external costs of renewable energy were put at 0.1–2.5 cents per kWh by the same study. From this perspective, the costs of environmental damage from fossil fuels can far outweigh the cost differences between renewables and fossil fuels [9,11,21,22].

Still, without external costs added, many say "renewables are too expensive." Costs of the most common renewable energy applications are shown in Table 5 [7]. In fact, some renewables are becoming competitive with coal and natural gas-fired power plants even without accounting for external costs. The high prices for oil and natural gas seen in recent years mean that the cost equation is changing. The cost of coal and natural gas power generation is largely a function of fuel prices, rather than power plant costs. Conversely, the cost of renewable energy is largely a function of initial investment cost. When comparing future costs, uncertainty must be included. The cost uncertainties of fossil-based power depend mostly on future fossil-fuel price volatility, while the cost uncertainties of renewable energy depend partly on technology cost reductions and partly on the future cost of capital. The difference, however, is that once a renewable energy facility is built, at least with fixed-rate financing, the cost of power from that facility is fixed throughout its lifetime [7,23].

In regions where the technology is well established, solar water heating is fully competitive with conventional water heaters, although less so in cooler climates where the solar resource is poorer and heating demand is higher. On the other hand, two key points emerge from the above discussion: if renewables are not yet competitive, they are getting

Table 5
Cost of renewable energy

Technology	Configuration	Levelized cost of energy (constant 1997 cents/kWh)				
		1997	2000	2010	2020	2030
Biomass	Direct fired	8.7	7.5	7.0	5.8	5.8
	Gasification based	7.3	6.7	6.1	5.4	5.0
Geothermal	Hydrothermal flash	3.3	3.0	2.4	2.1	2.0
	Hydrothermal binary	3.9	3.6	2.9	2.7	2.5
	Hot dry rock	10.9	10.1	8.3	6.5	5.3
Solar thermal	Power tower	–	13.6	5.2	4.2	4.2
	Parabolic trough	17.3	11.8	7.6	7.2	6.8
	Dish engine hybrid	–	17.9	6.1	5.5	5.2
	Dish engine solar only configuration	134.3	26.8	7.2	6.4	5.9
Photovoltaics	Utility-scale flat-plate thin film	51.7	29.0	8.1	6.2	5.0
	Concentrators	49.1	24.4	9.4	6.5	5.3
	Utility-owned residential	37.0	29.7	17.0	10.2	6.2
Wind	Horizontal axis turbines Class-4	6.4	4.3	3.1	2.9	2.8
	Horizontal axis turbines Class-6	5.0	3.4	2.5	2.4	2.3

Source: Ref. [7].

close; and cost comparisons can never be analytically precise, because they depend on assumptions about future fuel prices, interest rates, technology costs, treatment of external costs, and other conditions and thus leave room for analytical arbitrariness and bias. Aside from direct cost differences, many other market barriers have meant that most renewables continue to require policy support.

8.2. *Markets accelerate*

Renewable energy is now growing extremely quickly, in part due to strong policy support. The fastest growing energy technology in the world is grid-connected solar PV, which grew by 60% per year from 2000 to 2004. During the same 5-year period, other renewable energy technologies grew rapidly as well: wind power, 28%; biodiesel, 25%; solar hot water/heating, 17%; off-grid solar PV, 17%; geothermal heat capacity, 13%; and ethanol, 11% (all annual averages). Other renewable energy power generation technologies, including biomass, geothermal, and small hydro, are more mature and are growing by more traditional rates of 2–4% per year. Biomass heat supply is likely growing by similar amounts, although data are not available. These growth rates compare with annual growth rates of fossil fuel-based electric power capacity of typically 3–4%, a 2% annual rate for large hydropower, and a 1.6% annual rate for nuclear capacity during the 3-year period 2000–2002 [12,21,24].

Renewable energy competes with conventional fuels in four distinct markets: power generation, hot water and space heating, transport fuels, and rural (off grid) energy. In power generation, renewable power capacity reached 182 GW worldwide in 2005, more than 4% of the global power-generating capacity of 3900 GW. This capacity is primarily from small hydro (66 GW), wind (59 GW), and biomass power (44 GW), with smaller

amounts of solar PV (3 GW) and geothermal (9 GW). Solar thermal power (0.4 GW) and ocean power (0.3 GW) remain at low levels. Developing countries have almost half of the renewable power capacity at 80 GW. Hot water and space heating for tens of millions of buildings is supplied by solar, biomass, and geothermal. Solar thermal collectors alone are now used by an estimated 45 million households worldwide. Production of biofuels exceeded 37 billion liters in 2005, about 3% of the 1200 billion liters of gasoline consumed globally. Ethanol provided 41% of all (non-diesel) motor vehicle fuel consumed in Brazil in 2005. The most active markets are as follows [11,12,20,21,23]:

- *Solar PV:* Grid-connected solar PV installations are concentrated in Japan, Germany, and the United States. By 2005, more than 650,000 homes in these countries had rooftop solar PV feeding power into the grid. This market grew by about 1.1 GW in 2005, from 1.8 to 2.9 GW cumulative installed capacity.
- *Wind power:* Wind power markets are concentrated in a few primary countries, with Spain, Germany, India, and the United States leading expansion in 2005. India now has half of the wind power capacity of the United States and accounted for 15% of global installations in 2005. Several countries are now taking their first steps to develop large-scale commercial markets, including Russia and other transition countries, China, South Africa, Brazil, and Mexico.
- *Small hydropower:* More than half of the world's small hydropower capacity exists in China, where an ongoing boom in small hydro construction added 4.0 GW of capacity per year in 2004 and 2005. Other countries with active efforts include Australia, Canada, India, Nepal, and New Zealand.
- *Solar thermal power:* The concentrating solar thermal power market has remained stagnant since the early 1990s. Recently, commercial plans in Israel, Spain, and the United States have led to a resurgence of interest, technology evolution, and potential investment. New projects were under construction in 2006 in Spain and the United States. Some developing countries, including India, Egypt, Mexico, and Morocco, have planned projects with multilateral assistance.
- *Biomass energy:* Biomass electricity and heat production is slowly expanding in Europe, mainly driven by developments in Austria, Finland, Germany, and the United Kingdom. Among developing countries, small-scale power and heat production from agricultural waste is common from rice or coconut husks, for example. Use of sugar cane waste is significant in sugar-producing regions, including Brazil, Colombia, Cuba, India, the Philippines, and Thailand.
- *Geothermal energy:* There are at least 76 countries with geothermal heating capacity and 24 countries with geothermal electricity. More than 1 GW of geothermal power was added between 2000 and 2005, including increases in 2005. India now has half of the wind power capacity of the USA and accounted for 15% of global installations in 2005. Several countries are now taking their first steps to develop large-scale commercial markets, including Russia and other transition countries, China, Brazil, and Mexico.

8.3. Renewable energy utilization

More than half of the world's small hydropower capacity exists in China, where an ongoing boom in small hydro construction added 4 GW of capacity per year in 2004 and

2005. Other countries with active efforts include Australia, Canada, India, Nepal, and New Zealand.

The concentrating solar thermal power market has remained stagnant since the early 1990s. Recently, commercial plans in Israel, Spain, and the United States have led to a resurgence of interest, technology evolution, and potential investment. New projects were under construction in 2006 in Spain and the United States. Some developing countries, including India, Egypt, Mexico, and Morocco, have planned projects with multilateral assistance [23–26].

Biomass electricity and heat production is slowly expanding in Europe, mainly driven by developments in Austria, Finland, Germany, and the United Kingdom. Among developing countries, small-scale power and heat production from agricultural waste is common from rice or coconut husks, for example. Use of sugar cane waste (bagasse) is significant in sugar-producing regions, including Brazil, Colombia, Cuba, India, the Philippines, and Thailand.

There are at least 76 countries with geothermal heating capacity and 24 countries with geothermal electricity. More than 1 GW of geothermal power was added between 2000 and 2005, including increases in France, Guatemala, Iceland, Indonesia, Italy, Kenya, Mexico, New Zealand, the Philippines, and Russia. Geothermal heat capacity doubled from 2000 to 2005, with at least 13 countries using geothermal heat for the first time. Half of the heat capacity exists as heat pumps for building heating and cooling, with 2 million pumps in more than 30 countries [23,24].

Solar hot water/heating technologies contribute significantly to the hot water/heating markets in China, Europe, Israel, Turkey, and Japan. Dozens of other countries have smaller markets. Total installed capacity worldwide was 88 GWth in 2005. China accounts for 60% of this total, followed by Europe (13%), Turkey (7%), and Japan (6%). Total sales volume in 2005 in China was 15 million m^2 (10.5 GWth), a 23% increase in existing domestic capacity.

Brazil has been the world's leader of fuel ethanol for more than 25 years, producing about 15 billion liters in 2005, slightly less than half the world's total. All fueling stations in Brazil sell pure ethanol (E95) as well as gasohol, a 25% ethanol/75% gasoline blend (E25). There were more than 340 sugar mills and distilleries producing ethanol in Brazil by 2005. The USA is the second largest producer of fuel ethanol with more than 95 ethanol plants operating. On the other hand, biodiesel production almost doubled in Germany in 2005 to about two billion liters, bringing total world production to 3.9 billion liters. Other primary biodiesel producers are France and Italy, with several other countries producing smaller amounts, including Austria, Belgium, the Czech Republic, Denmark, Indonesia, Malaysia, and the United States [23,24,30,31].

9. Energy and environment Turkey

Turkey is located in the Northern Hemisphere at the junction of Europe and Asia. The European side is called Thrace and the Asian part is known as Anatolia. It shares boundaries with Greece, Bulgaria, Georgia, Armenia, Azerbaijan, Iran, Iraq and Syria with a total length of 2753 km. It holds a coastal length of 8333 km. This coastal zone includes the shores of Black Sea, The Sea of Marmara, Agean Sea, Mediterranean Sea and the passages of Bosphorous and Dardanelles. It has a total area of 78 million hectares of which 20.8 million hectares are designated as forest land. The topography is very rough

and steep. The country has 26 catchment area with 9 major river basins covering about half of the land area. The Southern Anatolia Project (GAP) covering 7500 km^2 is the country's most comprehensive and multisectoral integrated regional development project [32–34].

The government has made considerable efforts to address namely energy security, economic efficiency and environmental protection, in a sustainable manner. New legislation will reduce the role of the government in energy markets and strengthen market forces in the sector. An independent regulator (EMRA) has been established, an ambitious privatization programme has been announced, the United Nations Framework Convention on Climate Change (UNFCCC) has been ratified and the country is preparing legislation to address energy efficiency. A renewable energy law has been submitted to the Parliament for approval. Some important oil and gas transit pipeline projects are under way or nearing completion, which will improve the security of supply in Turkey and make it an important "energy corridor" between East and West. Investments have been made to extend domestic gas infrastructures and upgrade refineries. Nevertheless, Turkey still faces many challenges in all areas of energy policy [35–38].

Forecasts serving as a basis for the government's energy policy and energy enterprises' investment plans have been overestimating demand growth in Turkey, mainly owing to the previous overly optimistic assumptions of gross domestic product (GDP) growth and the effect of the economic crisis in 2001. While it is encouraging that most recent forecasts appear to be more realistic, the government needs to continue such efforts taking into account the effects of market liberalization and privatization. Despite significant efforts to liberalize the energy markets, Turkey continues to rely on its state-owned companies. Although privatization is not a prerequisite for market reform, it is necessary to restructure the state-owned enterprises into a corporate form operating under market competition and to prevent the Treasury from requesting annual income for the state budget. This would allow them to act as a player in the liberalized markets without government intervention, thus creating a level playing field [32,35,37].

Turkey has made significant progress with regard to environmental protection but more still needs to be done. The UNFCCC entered into force in May 2004. The country is in the process of developing its Climate Change Strategy and first national communication to the UNFCCC. The government should strive to monitor the effectiveness of the chosen policies and measures, both in terms of costs and emissions reductions. It should also consider defining an emissions target based on the momentum of the UNFCCC ratification. Coordination among the various government bodies will be key to the success of the strategy. Turkey has made significant progress in reducing local air pollution, particularly in large cities, but work remains to be done to ensure existing standards are met and to prepare for further reductions in air pollution. In this respect, it will be important to ensure that all market operators, including those owned by the State, comply with the existing air quality and emissions legislation. While investments have been made to increase security in the congested tanker traffic through the Turkish Straits, further action, such as seeking alternative transport routes, continued cooperation with other Black Sea nations and increased involvement of large oil and gas importing countries, appears necessary [32,35,37].

The general approach of Turkey's energy policy has been highly supply oriented, with emphasis placed on ensuring additional energy supply to meet the growing demand, while energy efficiency has been a lower priority. Consistently high-energy intensity and its imminent increase, partly attributable to the improving living standards, are matters of

concern. To realize an energy savings potential of 25–30%, an Energy Efficiency Strategy was developed in 2004 and the government is preparing an Energy Efficiency Law. These positive developments lift the status of energy efficiency and conservation as part of the government's energy policy but stronger policies beyond those in the law are still needed. The evident lack of a comprehensive and co-ordinated energy efficiency policy for the transport sector is of particular concern [35].

Natural gas accounts for 23% of total primary energy supply (TPES) in Turkey. Gas demand has been growing rapidly but the overestimated demand forecasts, caused principally by the 2000–2001 economic crisis, have led to some risk of oversupply because most of the imports are based on long-term take-or-pay contracts. The domestic gas network is being extended quickly to allow more consumers to access gas. The new gas storage facilities can help to meet peak demand but decisions to build storage facilities to cover seasonal peak supply should be made on the basis of economic criteria taking into account alternative approaches, namely more flexible supply contracts, interruptible consumers and multifiring in power plants. Large-scale gas transmission projects will enhance supply diversity, security of supply and competition in Europe and Turkey. However, their success will depend on the regulatory systems, including pricing, for gas transit, which will affect the viability of transit routes. It will also depend on the gas market reform given the large share of domestic consumption out of the total volumes of new pipelines [34–37].

The full implementation of the 2001 Natural Gas Market Law will substantially modify the gas market by transforming the monopolistic market structure into a competitive one through encouragement of new market entry and investments. While most of the necessary secondary regulation has been issued by EMRA and, in principle, 80% of the market is free to choose suppliers, competition has not developed because of the Petroleum Pipeline Corporation's (BOTAS's) defacto monopoly in imports. Other factors hampering competition are the lack of an independent transmission system operator (TSO) and incentives for eligible consumers to change suppliers owing to TPA tariff structures in the distribution networks. A flat price cap on all consumers constitutes cross-subsidies both between different consumer groups, notably from industrial consumers to residential consumers, and between different geographical areas [35,37].

The government wishes to maintain hard coal production to enhance fuel diversity, and consequently security of supply, but the policy is also closely related to social, regional and employment policies. Given its poor competitiveness, Turkish hard coal receives high and increasing subsidies per ton. The International Energy Agency (IEA) considers that these indefinite subsidies are not justified because the international market in hard coal is well established and offers secure and reliable sources of fuel at prices, both now and in the future, that Turkish national production cannot match. Furthermore, Turkey has large lignite resources, which make a far bigger contribution to its security of supply and are much more competitively priced than its hard coal resources ever could be. Nonetheless, there is a need for vigorous pursuit of productivity so that coal can compete as a fuel on equal grounds, even in the face of costs associated with tightening environmental requirements [32].

Turkey's use of hydropower, geothermal and solar thermal energy has increased since 1990. However, the total share of renewables in TPES has declined, owing to the declining use of non-commercial biomass and the growing role of natural gas in the system. The fixed feed-in tariffs and purchase obligation for distribution companies under the proposed

new Renewable Energy Law can encourage investments. The maximum level, 6 eurocents per kWh, is moderate as compared to the levels given, for example, to wind power in some other IEA member countries. While the scheme may not become excessively expensive for consumers, which is a common risk in feed-in tariffs, careful monitoring and adjustment of the cost of the scheme will be necessary until it is fully replaced by the purchase obligation in 2011. Given the diverse availability of resources among different distribution areas, it needs to be ensured that distribution companies can buy renewable electricity from certified producers located in other distribution regions to be able to fulfill their obligation at minimum cost. Despite a large potential for use of heat from renewables (geothermal, solar thermal and biomass), there are no specific policies in place for heat production from renewables [39,40].

Turkey has recently announced that it will reopen its nuclear program in order to respond to the growing electricity demand while avoiding increasing dependence on energy imports. The competitiveness of nuclear power in a liberalized electricity market in Turkey needs to be clarified. Investment decisions should be made on the basis of efficient and transparent price signals regardless of whether power plants are being built by private or public companies. Furthermore, waste disposal options need to be defined from the outset of launching a nuclear power project [39,40].

Despite a high reserve margin of 40%, Turkey will need more capacity in the midterm because electricity demand will continue to grow rapidly. The recently launched rehabilitation program for the thermal power plants to increase their efficiency is a prudent approach as it postpones the need to invest in new capacity. Nonetheless, new capacity will be needed in the next decade, which requires a good investment climate. Despite some reductions in distribution losses during the last couple of years, both technical and non-technical losses (totaling about 18% in 2004) are still a concern. One notable development is the progress in the project to interconnect with the European Union for the Co-ordination of Transmission of Electricity (UCTE) network, which is scheduled for 2006 [35,37,40].

To date, there have been cross-subsidies in electricity prices both between different consumer groups, notably from industrial consumers to residential consumers, and between different geographical areas. It is positive that the government has announced that energy prices for each consumer group will be based on cost and that transparent tariff calculation rules have been established by the regulator. However, regional cross-subsidies will remain at least for the next 5 years. On the other hand, the government should be highly commended for the initiative to create competitive electricity markets. The steps taken so far have created a window of opportunity to implement successful reform with clear and significant benefits. Now, decisive action will need to be taken to see the process through to a successful conclusion [35,37].

The adoption of the 2001 Electricity Market Law was a major milestone. It established EMRA, which has issued most of the necessary secondary legislation. The legislation has been supplemented by the 2004 Electricity Strategy. Despite the good legislative and regulatory framework, not much competition has developed for a number of reasons. There is a lack of consumer choice caused by the small number of market players; new entrants have difficulties competing with the state-owned incumbent who owns competitive depreciated generation units, including hydropower. Furthermore, the current generation overcapacity and lack of cost-reflective prices have made new investment unattractive. In addition, the Build-Own-Operate (BOO) and Build-Operate-Transfer

(BOT) schemes have a relatively high market share and only 29% of the market has been made eligible to choose suppliers. The Electricity Strategy contains the key elements for tackling these issues, including the privatization of EUAS, and handling the stranded cost issues caused by the BOO and BOT schemes. However, it will also be important to consider if the share of the liberalized market can be increased sooner than planned and to ensure that the transmission system and market operator (TEIAS) is independent from government control in its normal operation. Establishment of an electricity exchange would facilitate trade and introduce more competition. Cost-reflective pricing will be vital [32].

Turkey has dynamic economic development and rapid population growth. It also has macro-economic, and especially monetary, instability. The net effect of these factors is that Turkey's energy demand has grown rapidly almost every year and is expected to continue growing, but the investment necessary to cover the growing demand has not been forthcoming at the desired pace. On the other hand, Turkey's primary energy reserves (see Table 6) are not enough to meet energy demand. Turkey is an energy importing nation with more than 74% of total energy consumption (see Tables 7 and 8) met by imported fuels such as oil, natural gas and hard coal (see Figs. 1 and 2).

9.1. Oil

Turkey had 300 million barrels of proven oil reserves as of January 2006. During the first 9 months of 2006, Turkey produced an estimated 43,000 barrels per day (bbl/d) of oil, of

Table 6
Primary energy reserves in Turkey (2002)

Energy sources	Proven	Probable	Possible	Total
Hard coal (million ton)	428	456	245	1129
Lignite (million ton)				
Elbistan	3357			3357
Others	3982	626	110	4718
Total	7339	626	110	8075
Asphaltite	45	29	8	82
Bitumes	555	1086		1641
Hydropower				
GWh/yr	126,109			126,109
MW/yr	35,539			35,539
Petroleum (million ton)	39			39
Natural gas (billion m^3)	10.2			10.2
Nuclear sources (ton)				
Uranium	9129			9129
Thorium	380,000			380,000
Geothermal (MW/yr)				
Electricity	200		4300	4500
Thermal	2250		28,850	31,100
Solar energy				
Electricity				8.8
Heat				26.4

Source: Ref. [37].

Table 7
Present and future total final energy production in Turkey (Mtoe)

Energy sources	2000	2005	2010	2020	2030
Coal and lignite	13.29	20.69	26.15	32.36	35.13
Oil	2.73	1.66	1.13	0.49	0.17
Gas	0.53	0.16	0.17	0.14	0.10
Com. renewables and wastes[a]	6.56	5.33	4.42	3.93	3.75
Nuclear	–	–	–	7.30	14.60
Hydropower	2.66	4.16	5.34	10.00	10.00
Geothermal	0.68	0.70	0.98	1.71	3.64
Solar/wind/other	0.27	0.22	1.05	2.27	4.28
Total production	26.71	34.12	39.22	58.20	71.68

Source: Ref. [35].
[a]Comprises solid biomass, biogas, industrial waste and municipal waste.

Table 8
Present and future total final energy consumption in Turkey (Mtoe)

Energy sources	2000	2005	2010	2020	2030
Coal and lignite	23.32	35.46	39.70	107.57	198.34
Oil	31.08	40.01	51.17	71.89	102.38
Gas	12.63	42.21	49.58	74.51	126.25
Com. renewables and wastes[a]	6.56	5.33	4.42	3.93	3.75
Nuclear	–	–	–	7.30	14.60
Hydropower	2.66	4.16	5.34	10.00	10.00
Geothermal	0.68	1.89	0.97	1.71	3.64
Solar/wind/other	0.27	0.22	1.05	2.27	4.28
Total primary energy consumption	77.49	129.63	152.22	279.18	463.24

Source: Ref. [35].
[a]Comprises solid biomass, biogas, industrial waste and municipal waste.

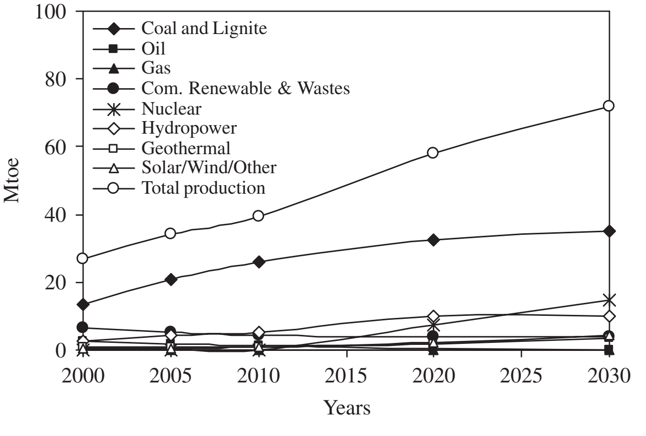

Fig. 1. Turkey's primary energy production during 2000–2030.

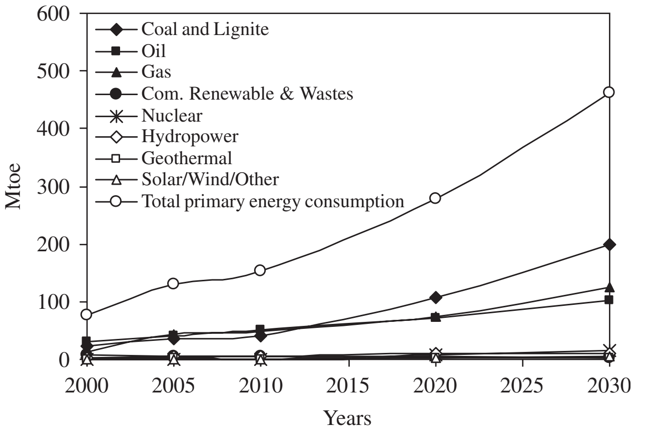

Fig. 2. Turkey's primary energy consumption forecast 2000–2030.

which 99% was crude oil. Turkey's oil production has declined by half since 1991, when production peaked at 85,300 bbl/d. EIA forecasts that Turkey will consume 618,000 bbl/d of oil in 2006, down about 4% from 2005 figures. In general, Turkish oil demand has fluctuated in recent years along with the country's economic performance [35–37].

Turkey's oil sector is mixed, comprised of various state-owned, private, and foreign companies. Oil exploration and production activities are dominated by the state-owned Turkish Petroleum Corporation (TPAO), which accounts for roughly 70% of Turkey's domestic oil output. The principal government body charged with monitoring the oil sector is the Ministry of Energy and Natural Resources (ETKB), which is the key decision-making body that approves new projects along with the State Planning Organization (DPT).

The downstream oil refining and storage sector is dominated by former state-owned enterprise TUPRAS, which controls 85% of Turkey's domestic refining activities. In September 2005, the Koc-Shell Joint Venture Group purchased a 51% stake in Tupras for $4.14 billion. In December 2003, a petroleum market reform bill was passed by Turkey's parliament. The Petroleum Market Law aims to remove state controls on the hydrocarbon sector, liberalize pricing of oil and oil products, end restrictions on vertical integration, and integrate pipeline, refining, and distribution functions. Also, as a result of this law, price ceilings and import quotas on petroleum products were lifted in early 2005 [32–38].

The majority of Turkey's oil reserves are located in southeastern part of the country and in the Thrace region in the northwest. The oil fields in the southeastern Hakkari Basin, Turkey's main oil producing region, are mature and output has declined over the last decade. Furthermore, production costs for oil reserves in the Hakkari Basin are considered higher than average international levels. Recent oil exploration activities have focused on Turkey's offshore regions, where the country holds oil prospects in the Black, Mediterranean, and Aegean Seas. Although some reports suggest the Aegean Sea could hold sizeable oil reserves, potential oil reserves in the region have not been explored due to conflicting Greek claims over the area. During 2005, TPAO and its international partners drilled the country's first exploration wells in the Black Sea [32–38].

9.2. Natural gas

Turkey had 300 billion cubic feet (Bcf) of proven natural gas reserves as of January 2006. Although Turkey does not have sizeable reserves, it is an important natural gas transit country. Turkey is also a growing consumer of natural gas in its own right, with consumption having increased significantly over the last decade. In 2004, Turkey consumed 793 Bcf of natural gas, up 51% since 2000, while only producing 24 Bcf of natural gas [33,35].

Prior to 2001, Turkey's natural gas market and infrastructure were almost entirely dominated by state-owned BOTAS. In May 2001, Turkey enacted a new Natural Gas Market Law with the intent to liberalize the natural gas sector, encourage foreign investment in energy infrastructure, and harmonize its energy policy with that of the EU. Among other things, the law will abolish the BOTAS monopoly, separating the company into units for natural gas import, transport, storage, and distribution by 2009. At that point, the various components (except for transport) are to be privatized. However, this process has proceeded slowly, and many expect the 2009 deadline to be pushed back. Turkey's Energy Market Regulatory Authority (EMRA) is responsible for implementing the Natural Gas Market Law, and also now sets natural gas prices in Turkey [33,35].

9.3. Coal

Turkey has significant coal reserves, especially lignite, but also some hard coal. At end of 2002, hard coal reserves were estimated at about 1.13 billion tons, 428 million tons of which were proven reserves (Table 3). Hard coal is found and mined in only one location, the Zonguldak basin near the north-western Black Sea coast and mine is operated by the fully state-owned Turkish Hard Coal Enterprise (TTK). Hard coal production has declined since the mid-1980s, falling from 2.7 million tons in 1990 to 2.4 million tons in 2002. TTK is trying to reserve this trend and aims to increase production to 3 million tons [37].

Total proven lignite reserves were estimated at about 8.1 billion tons (see Table 8). Turkish lignite has low calorific value and high sulphur, dust and ash content. Turkish hard coal is of low grade but of cokeable or semi-cokeable quality. The most important reserves are in the Afsin-Elbistan, Beypazarı, Mugla, Soma, Seyitomer, Tuncbilek, and Sivas regions. About 40% of the country's lignite resources (about 3.4 billion tons) are situated in the Afsin-Elbistan basin in the South-Eastern part of the country. Much of the remainder and over half of all lignite production are located in the western parts of the country. About 90% of lignite production is open-cast, but low-cost open-cast mines are nearing depletion. There are also asphaltite reserves of 82 million tons in the Sirnak and Silopi areas [35–37].

The state-owned Turkish Hard Coal Enterprises (TTK) has a de facto monopoly in hard coal production, processing, and distribution, although there are no legal restrictions on private sector involvement. State-owned and private companies produce, process, and distribute lignite reserves, although state-owned Turkish Coal Enterprises (TKJ) has a majority market share. Restructuring of Turkey's coal sector has been underway since the 1990s, with a final goal of eventually privatizing TTK and TKJ as well as closing down smaller, less profitable mines [37].

9.4. Electricity

In 2004, Turkey had a total installed electricity generating capacity of 35.6 gigawatts (GW), a 36% increase since 2000. The country produced 143 billion kWh of electricity in 2004, while consuming 133 billion kWh. Conventional thermal sources comprise the largest share of Turkey's electricity supply, contributing 68% in 2004. Hydroelectricity generation makes up almost all of the remainder. Although Turkey does not currently produce any nuclear energy, the country's first nuclear power plant is expected to begin electricity generation in 2012 [33]. Table 9 gives Turkey's production of electricity by source (see Fig. 3). Table 10 is also gives the present and future electric power capacity development in Turkey. As shown in Tables 9 and 10, the electric power production capacity is increasing quickly due to rapid population and economic growing (also see Fig. 3).

In March 2001, the Turkish government enacted a new Electricity Market Law, which sets the stage for liberalization of power generation and distribution activities. Under the law, the state-owned Turkish Electricity Generation and Transmission Corporation (TEAS) was split into separate generation, distribution, and trade companies, with a goal of eventual privatization of the generation and trade companies. Transmission of electricity will continue to be run by the state [32–35]. After the passage of the Electricity Market Law, TEAS was

Table 9
Turkey's production of electricity by source (GWh)

Energy sources	1970	1980	1990	2000	2002	2004
Fossil fuels	5425	11,792	34,315	93,714	95,389	104,360
Hard coal	1382	912	621	3819	4090	11,996
Lignite	1442	5049	19,561	34,367	28,056	22,450
Natural gas	–	–	10,192	46,217	52,497	62,242
Nuclear	–	–	–	–	–	–
Renewables	3199	11,484	23,228	31,208	34,010	46,339
Total production	8623	23,275	57,543	124,922	129,400	150,698
Total consumption	7308	20,398	46,820	98,296	102,948	121,142

Source: Ref. [37].

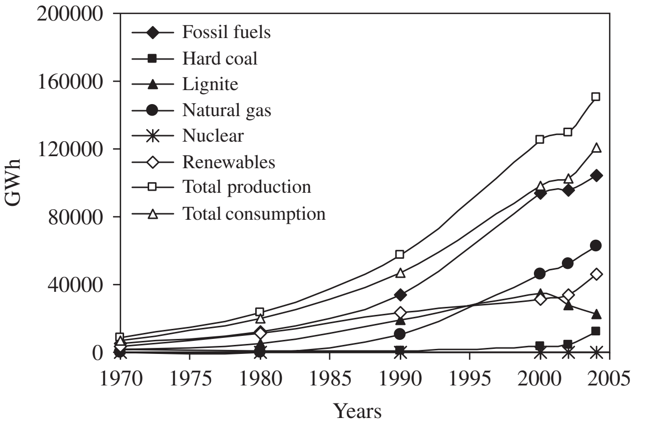

Fig. 3. Turkey's electricity production during 1970–2005.

Table 10
Present and future electric power capacity development in Turkey

Fuel type	2005		2010		2020	
	Installed capacity (MW_e)	Generation (GWh)	Installed capacity (MW_e)	Generation (GWh)	Installed capacity (MW_e)	Generation (GWh)
Coal	14,465	48,386	16,106	104,040	26,906	174,235
Natural gas	10,756	66,417	18,923	125,549	34,256	225,648
Fuel oil	2124	10,531	3246	18,213	8025	49,842
Renewables[a]	14,112	50,900	25,102	86,120	30,040	104,110
Nuclear	0.0	0.0	2000	14,000	10,000	70,000
Total	41,457	176,234	65,377	347,922	109,227	623,835

Source: Ref. [35].
[a]Renewables includes hydropower, biomass, solar, and geothermal energy.

split into separate state-owned companies: Turkish Electricity Generation Company (EUAS), Turkish Electricity Transmission Company (TEIAS), and Turkish Electricity Trading and Contracting Company (TETAS). Before the 2001 reforms, EUAS operated 91% of Turkey's power supply. However, EUAS will sell off most of its power plants and other holdings under the government's privatization plan. In June 2003, 27 state-owned coal and hydropower plants were transferred to a government holding company in preparation for privatization, accounting for 28% of the Turkish power generating market [33–35].

9.4.1. Conventional thermal

Conventional thermal sources have historically been Turkey's largest power source. Natural gas-fired power plants have increased substantially in the last decade and now comprise more than half of the country's conventional thermal generation. However, in July 2006, two natural gas-fired power plants ceased operations, with the operator AK Enerji citing increasing natural gas costs. On the other hand, the company complained that natural gas prices for power producers have risen by 50% over the last year while the government-set electricity tariff for consumers has not changed. Still, plans for natural gas-fired power stations abound in Turkey, especially given that the country has contracts to purchase significant amounts of natural gas in the future [33].

Coal-fired power stations also remain an important energy source for Turkey, and there is renewed interest in exploiting Turkey's domestic coal resources following large natural gas price increases. In August 2006, tenders were offered by EUAS for the construction of two new 1200-MW coal-fired units at the existing Afsin-Elbistan power plant. The Afsin-Elbistan region holds 3.3 billion short tons of lignite reserves, or 40% of Turkey's domestic total. Over the last few years, several new conventional thermal power plants have come online. However, except for the recent EUAS tender, few new power stations are currently scheduled to be built in Turkey [33–35].

9.4.2. Hydroelectric

Turkey has significant hydroelectric power resources, with more than 100 total plants and total installed hydroelectric generating capacity of 12.6 GW. Turkey is also developing

a great deal more of hydropower plants, especially as part of the $32 billion Southeastern Anatolia Project (GAP) along the basin of the Tigris and Euphrates Rivers. Under the GAP project, which is considered one of the most ambitious water development projects ever undertaken, Turkey will erect 22 dams, 19 hydroelectric power stations (with around 7.5 GW of generating capacity), and an expansive network of tunnels and irrigation canals covering 1.7 million hectares of land. The GAP project is overseen by the Southeastern Anatolia Project Regional Development Administration [43]. By the end of 2005, eight hydropower plants had been completed, representing 74% of total planned energy projects under the GAP scheme. The eight power stations generated 18.7 billion kWh of electricity in 2005, adding substantially to the share of hydroelectricity in Turkey's energy mix. The entire GAP project is scheduled to be completed by 2010. Table 11 shows the hydropower potential in Turkey [39–44].

9.4.3. Nuclear

In April 2006, the head of Turkey's Atomic Energy Agency (TAEK) confirmed that Turkish Prime Minister Recep Tayyip Erdogan had chosen the Black Sea port of Sinop to be the site of the country's first nuclear power plant. The site was one of eight identified by TAEK as a potential location for the power plant following a careful technical evaluation. The 1800-MW power plant, which will cost an estimated $2.7 billion to construct, is scheduled to come online in 2014. Turkey originally hoped to build three new nuclear plants totaling 5000 MW, but plans have been scaled back. Although Turkey is proceeding with its nuclear ambitions, there are still numerous obstacles facing the Sinop project. Turkey has tried to move ahead with plans to build a nuclear power plant for more than 30

Table 11
Distribution of the hydropower potential in Turkey by Project implementation status

	Number of project	Installed capacity (MW)	Total annual power generation capacity				
			Firm (GWh)	Mean (GWh)	Cumulative (GWh)	Mean (%)	Cumulative (%)
In operation	130	12,251	32,984	44,388	44,034	35.0	35.0
Under construction	31	3338	6467	10,845	55,233	9.0	44.0
Final design completed	19	3570	7029	10,897	66,130	9.0	52.0
Under final design operation	21	1333	2492	4494	70,624	4.0	56.0
Planned	119	6091	10,861	22,324	92,948	18.0	74.0
Under planning	57	1978	4214	7602	100,550	6.0	80.0
Master plan completed	40	2691	5674	9195	109,745	7.0	87.0
Reconnaissance completed	107	3920	8523	15,184	124,929	12.0	99.0
Initial study completed	42	368	526	1180	126,109	1.0	
Total potential	566	35,540	78,770	125,129		100.0	

Source: Ref. [44].

years, but the plans have been blocked by difficulties attracting sufficient financing, legal issues, and opposition from environmental and anti-nuclear groups [33,35].

9.4.4. Other renewables

Other renewable sources add very little to Turkey's total electricity supply, contributing only about one tenth of 1% to Turkey's electricity generation in 2004. However, Turkey is considered to have a large amount of wind, geothermal, and solar power potential, and a number of projects to exploit these sources are underway. However, renewable energy sources are not likely to contribute significantly to Turkey's energy mix in the near term [45–50].

Among the renewable energy sources, biomass is important because its share of total energy consumption is still high in Turkey. Since 1980, the contribution of the biomass resources in the total energy consumption dropped from 20% to 8% in 2005. Biomass in the forms of fuelwood and animal wastes is the main fuel for heating and cooking in many urban and rural areas [51,52]. The total recoverable bioenergy potential is estimated to be about 16.92 Mtoe in 1998. The estimate is based on the recoverable energy potential from the main agricultural residues, livestock farming wastes, forestry and wood processing residues, and municipal wastes that given in the literature [52]. On the other hand, fuelwood is important for rural area in Turkey as in other developing countries. About half of the world's population depends on fuelwood or other biomass for cooking and other domestic use. In 2000, an estimated 13 million steres of fuelwood were produced by the state, while from both public and private sectors recorded production was estimated at about 14.2 million steres from undeclared production. In other words, approximately half of the total demand for fuelwood is met by informal cutting in State forests and other sources of fuelwood in agricultural areas.

Turkey is one of the countries with significant potential in geothermal energy. Data accumulated since 1962 show that there may exist about 4500 MW of geothermal energy usable for electrical power generation in high enthalpy zones. Heating capacity in the country runs at 350 MWt equivalent to 50,000 households. These numbers can be heightened some seven-fold to 2250 MWt equal to 350,000 households through a proven and exhaustible potential. Turkey must target 1.3 million house holds equivalent 7700 MWt. Geothermal central heating, which is less costly than natural gas could be feasible for many regions in the country. In addition 31,000 MW of geothermal energy potential is estimated for direct use in thermal applications. The total geothermal energy potential of Turkey is about 2268 MW in 1998, but the share of geothermal energy production, both for electrical and thermal uses is only 1229 MW. There are 26 geothermal district heating systems existing now and the main city geothermal district heating systems are in Gönen, Simav, and Kırşehir cities [53,54].

The yearly average solar radiation is 3.6 kWh/m^2-day and the total yearly radiation period is approximately 2640 h, which is sufficient to provide adequate energy for solar thermal applications in Turkey. In 2004, about 8.0 million m^2 solar collectors were produced and it is predicted that total solar energy production is about 0.290 million ton of oil equivalent (Mtoe). Although solar energy is the most important renewable energy source it has not yet become widely commercial even in nations with high solar potential such as Turkey. Thermosyphon-type flat plate collectors have been used in Turkey since 1950, and at present about 30% of installed systems are still of this type. Typical solar water heaters in Turkey are of the thermosyphon type and consists of two flat-plate solar

collectors having an absorber area between 3 and 4 m^2, a storage tank with capacity between 150 and 200 l and a cold water storage tank, all installed on a suitable frame [55–58].

The energy consumption for heating and cooling of buildings in Turkey was about 21.6 Mtoe for the year 2005. This is more than one third of the total energy consumption. The average household in Turkey needs more that 60% of its total energy consumption for space heating. The cooling demand in buildings increased rapidly in south region of the country at the summer season. The reason, beside general climatic and architectural boundary conditions, is an increase in the internal cooling load and higher comfort requirements. These aspects show the huge potential in this field for the implementation of advanced thermal energy storage technologies in Turkey. On the other hand, solar and ground coupled heat pumps can be used for both heating and cooling of the building in most regions of Turkey [59–62].

Turkey, currently, does not have an organized PV program. Government has no intention in PV production. There are more than 30,000 small residential areas where solar-powered electricity would likely be more economical than grid supply. Another potential for PV market is holiday villages at the long coastal areas. These facilities are frequently far from the main grid nodes and require additional power when solar insolation is high. The newest 5 years development plan, being prepared, foresees a more ambitious program and estimates approximately 40 MWp installed power by the year 2010 [58].

There are a number of cities in Turkey with relatively high wind speeds. These have been classified into six wind regions, with a low of about 3.5 m/s and a high of 5 m/s at 10 m altitude, corresponding to a theoretical power production between 1000 and 3000 kWh/(m^2 yr). The most attractive sites are the Marmara Sea region, Mediterranean Coast, Agean Sea Coast, and the Anatolia inland. Turkey's first wind farm was commissioned in 1998, and has a capacity of 1.5 MW. Capacity is likely to grow rapidly, as plans have been submitted for just under a further 600 MW of independent facilities. The majority of proposed projects are located in the Çeşme, İzmir, and Çanakkale regions [63–66].

Wind power potential in Turkey amounts to approx. 83 GW, and according to other estimates it is as high as 116 GW. Approximately 10% of this potential can be feasibly used, especially in the country's extended coastal regions. Wind energy is not very highly developed in Turkey so far when measured against the potential, and it has a relatively brief history. At the end of 2000 a total of 19.2 MW was installed in Turkey, distributed between three locations: Germiyan/Izmir with 1.6 MW, Bozcaada/Canakkale with 10.2 MW, and Alaçati/Izmir with 7.4 MW [63].

9.5. Environment in Turkey

The environmental damage cited includes severe air and water pollution, destruction of certain ecosystems across large regions, pervasive losses of natural habitat, and the reduction of plant and animal biodiversity. Most of these impacts are expected to continue in coming decades. On the other hand, Turkey's explosive economic growth in the mid-1990s had significant repercussions on the country's environment. Economic growth and energy consumption have gone hand-in-hand, and the effect has been increasing air pollution in cities that are already suffering from high pollution levels. Although low

compared to advanced European economies, Turkey's per capita carbon emissions are increasing. In a good faith measure to help gain entry into the EU, Turkey ratified the Kyoto Protocol aimed at reducing global GHG emissions in 2004, although the country does not have a formal emissions reduction target [67–73].

Turkey has been undergoing major economic changes in the 1990s, market by rapid overall economic growth and structural changes. However, the share of the informal sector in the Turkish economy remains high. Turkey's population has reached 72 million and remains one of the fastest growing from 1990 to 2004 in the OECD. Major migrations from rural areas to urban, industrial and tourist areas continue. In this context, Turkey confronts the challenge of ensuring that economic growth is associated with environmental and social progress, namely that its development is sustainable [32–34].

Turkey ratified the Framework Convention on Climate Change in February 2004 and is developing its climate change strategy. After that, on May 24, 2004 Turkey became the 189th party by signing Framework Convention on Climate Changes. In the first 6 months after Turkey became a party of FCCC, the country is obligated to first national declaration to United Nations General Secretariat until November 24, 2004. After this stage is completed Turkey will both have to fulfill new liabilities such as to present national GHG inventories and national declaration reports to Convention Secretariat regularly, and will also actively participate in efforts carried on global wide so that convention will achieve its ultimate goal. In 2003, it is estimated that 36% of CO_2 emissions occurred due to energy, 34% due to industry, 15% due to transportation and 14% due to other sectors such as housing, agriculture, and forestry and in 2020 40% will occur due to energy, 35% due to industry, 14% due to transportation, and 11% due to other sectors [32–35].

10. Turkey's energy future

Turkey's demand for energy and electricity is increasing rapidly. Since 1990, energy consumption has increased at an annual average rate of 4.3%. As would be expected, the rapid expansion of energy production and consumption has brought with it a wide range of environmental issues at the local, regional, and global levels [72]. With respect to global environmental issues, Turkey's carbon dioxide (CO_2) emissions have grown along with its energy consumption. Emissions in 2000 reached 211 million metric tons [32–35]. Table 12 shows direct GHG emissions in Turkey by sectors between 1990 and 2010 [73].

Based on the demand forecast from MAED, total final energy consumption grows at an average rate of 5.9% per year from 65.5 Mtoe (2000) to 273.5 Mtoe (2025). Average annual growth rates vary by sector, with industry having the highest rate at 7.6%, followed by the transportation sector with 5.0% [72]. On the other hand, total natural gas consumption is projected to increase at an annual rate of 9.6% from 15.0 to 169.4 billion m^3 (bcm) over 2000–2025. Power sector gas demand is one of the main drivers for this projected growth and will account for 112.8 bcm or 67% of total gas consumption in 2025 (up from 9.3 bcm in 2000). Industrial demand is the fastest growing market segment (11.5% annually) with gas expanding from 2.5 to 38.4 bcm during 2000–2025 and eventually accounting for 23% of total gas consumption.

New capacity additions are projected to total about 108 GW by 2025. WASP results indicate that the majority of the load growth is met with natural gas-fired generation [32–36,72]. By 2025, gas-fired units represent 67% (93 GW) of the installed generating capacity and account for 77% of total generation (588 of 768 TWh). On the other hand,

Table 12
Direct greenhouse gas emissions in Turkey by sectors between 1990 and 2010 (%)

Greenhouse gases (GHG)	Years					
	1990	1995	1997	2000	2005	2010
Total direct GHG (Gg)[a]	200,720	241,717	271,176	333,320	427,739	567,000
CO_2 (%)	88.67	87.42	88.93	90.93	92.90	94.53
CH_4 (%)	10.77	10.05	9.42	7.68	5.97	4.52
N_2O (%)	0.56	2.53	1.65	1.40	1.14	0.95
Emission fractions generated from fuel consumption						
Direct GHG (Gg)[a]	146,735	172,933	195,591	258,314	352,733	491,995
CO_2 (%)	97.3	97.8	98.0	98.2	98.6	98.9
CH_4 (%)	2.1	1.6	1.5	1.4	1.0	0.7
N_2O (%)	0.6	0.5	0.5	0.4	0.4	0.4
Emission fractions generated from industrial processes						
Direct GHG (Gg)[a]	35,424	47,251	52,929	52,929	52,929	52,929
CO_2 (%)	99.5	89.1	93.5	93.5	93.5	93.5
CH_4 (%)	0.1	0.1	0.1	0.1	0.1	0.1
N_2O (%)	0.4	10.8	6.4	6.4	6.4	6.4
Emission fractions generated from the burning of agricultural residues						
Direct GHG (Gg)[a]	591.05	550.25	578.5	578.5	578.5	578.5
CH_4 (%)	76.92	76.90	76.96	76.96	76.96	76.96
N_2O (%)	23.08	23.10	23.04	23.04	23.04	23.04

Source: Ref. [73].
[a]Direct greenhouse gases, CH_4, and N_2O emission values were given as CO_2 equivalents.

primary energy supply is projected to increase from 64.5 Mtoe (1995) to 332.0 Mtoe (2025). Crude oil imports remain constant at 33.0 Mtoe after 2004 when the domestic refineries are forecast to run into their processing capacity, resulting in a drop in crude oil share from 44% to 10% of total supplies. Once the refining capacity is reached, net imports of refined products quickly grow from 2.6 to 52.3 Mtoe (2000–2025), accounting for about 16% of total supplies by 2025. Natural gas quickly increases its share from 10% (6.3 Mtoe) in 1995 to 42% (139.8 Mtoe) of total supplies in 2025. Although renewables double over 2000–2025, their share decreases from 14% in 2000 to 7% in 2025.

The model projects total CO_2 emissions to increase at an average rate of 5.8%/yr and reach 871 million tons/yr by 2025. The industrial contribution changes the most noticeably, rising from 31% to 42% driven by the high growth in industrial final energy as well as the continued reliance on solid and liquid fuels in this sector [72]. Total national SO_2 emissions reach their low point as 1.83 million tons/yr in 2001, but it will be more than double value to 3.85 million tons/yr in 2025. The majority of the emissions growth can be attributed to an increase in industrial solid fuel and fuel oil combustion and an associated rise in SO_2 emissions from 566 to 2411 kt/yr over 2000–2025. By the end of the study period, industry is expected to be responsible for 63% of Turkey's SO_2 emissions [73]. While in 2004, electricity generation accounted for 60% of national sulfur emissions, this share will be down to 24% by 2025. This is in large part because coal generation stays more or less constant while several new sulfur controls are already commissioned and expected to come on-line in the very near term.

11. Conclusions

Turkey, with its young population and growing energy demand per person, its fast growing urbanization, and its economic development, has been one of the fast growing power markets of the world for the last two decades. It is expected that the demand for electric energy in Turkey will be 300 billion kWh by the year 2010 and 580 billion kWh by the year 2020. Turkey is heavily dependent on expensive imported energy resources that place a big burden on the economy and air pollution is becoming a great environmental concern in the country. In this regard, renewable energy resources appear to be the one of the most efficient and effective solutions for clean and sustainable energy development in Turkey. Turkey's geographical location has several advantages for extensive use of most of these renewable energy sources.

Renewable energy supply in Turkey is dominated by hydropower and biomass, but environmental and scarcity-of-supply concerns have led to a decline in biomass use, mainly for residential heating. As a contributor of air pollution and deforestation, the share of biomass in the renewable energy share is expected to decrease with the expansion of other renewables. On the whole, Turkey has substantial reserves of renewable energy sources, including approximately 1% of the total world hydropower potential. There is also significant potential for wind power development. Turkey's geothermal potential ranks seventh worldwide, but only a small portion is considered to be economically feasible.

During the next 30 years, renewables will become even more affordable and economically competitive with fossil fuels. As initial capital and research and development costs are amortized, renewables will continue to provide electricity at low marginal cost. The cheapest reserves of fossil fuels have already been exploited, however, and these fuels will become increasingly expensive to use. This shift can be hastened by wise policy incentives and an increase in research and development funding for renewable energy so that renewable sources can meet the world's energy and environmental needs in the twenty-first century.

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